July 17, 1934. A. HUND 1,967,008

ELECTRICAL AMPLIFIER

Filed Nov. 5, 1931 3 Sheets-Sheet 1

Fig. 1

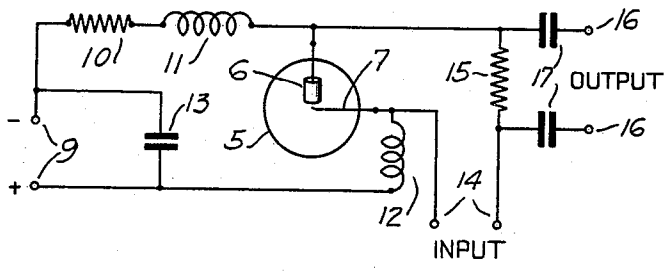


Fig. 2

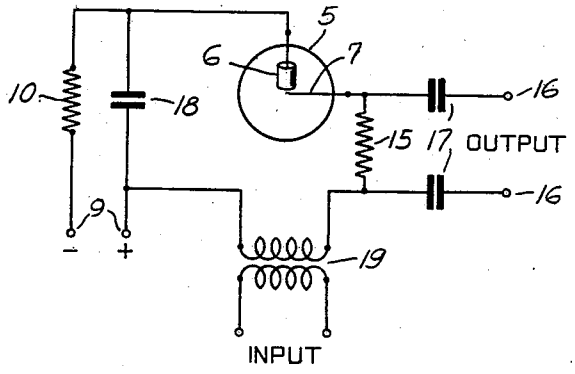
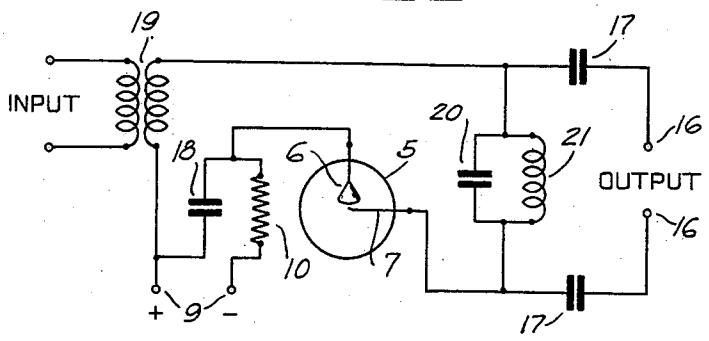


Fig. 3



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Filed Nov. 5, 1931 3 Sheets-Sheet 2

Fig. 4

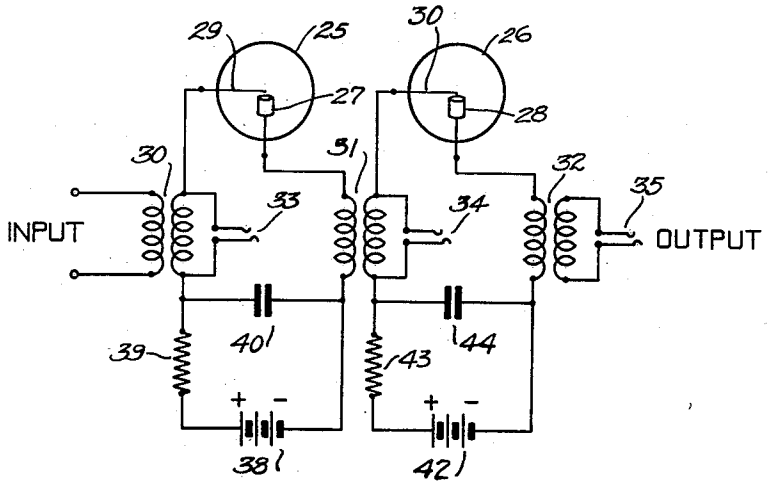
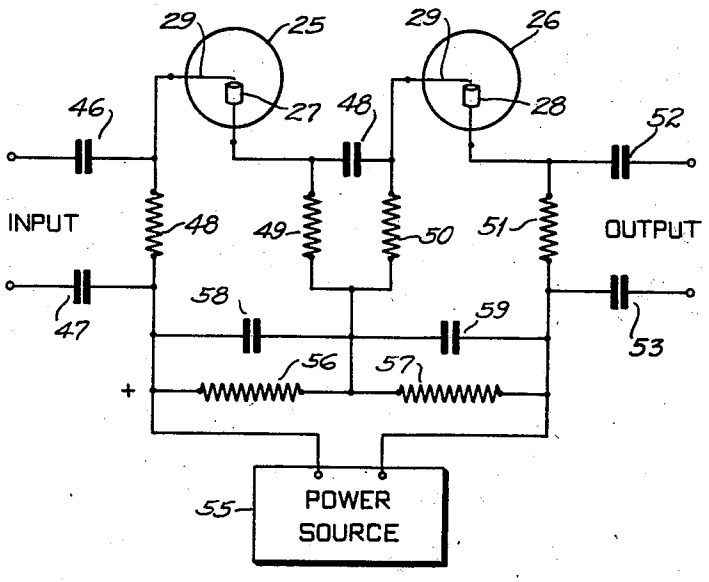


Fig. 5



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Filed Nov. 5, 1931 3 Sheets-Sheet 3

Fig. 6

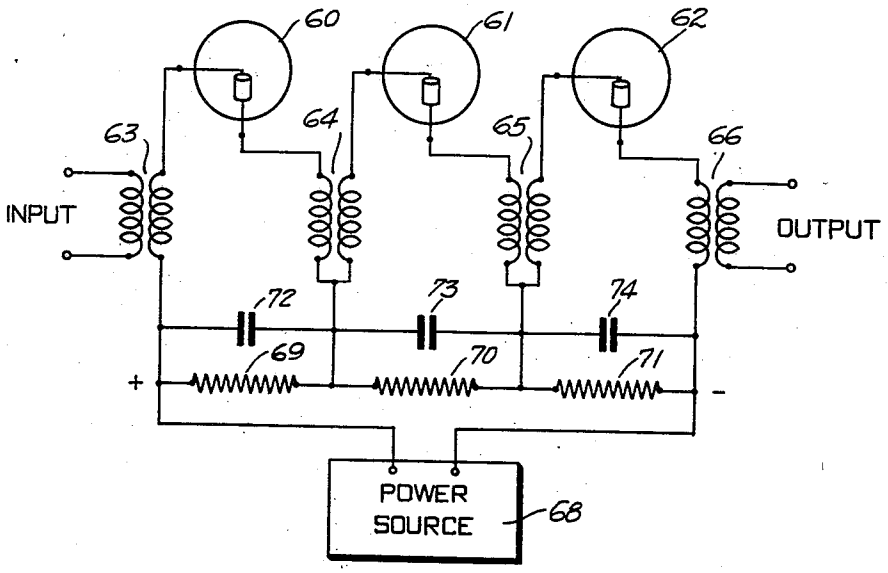


Fig. 7

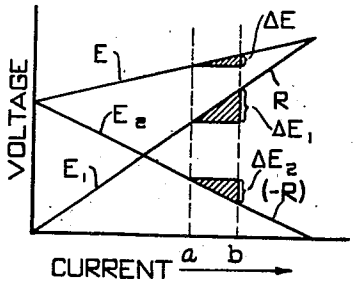
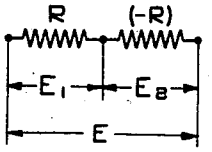


Fig. 8



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UNITED STATES PATENT OFFICE

1,967,008

ELECTRICAL AMPLIFIER

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Application November 5, 1931, Serial No. 573,076

6 Claims. (Cl. 179—171)

This invention relates to electrical discharge tubes and circuits therefor, and particularly to most types of glow discharge devices, for use as amplifiers of electrical potential differences.

The object of the invention is to efficiently amplify electrical voltages and currents with fidelity.

Another object of the invention is to produce amplification of electrical potentials by use of glow discharge devices having a negative characteristic.

A further object of the invention is to produce a stable negative resistance characteristic in a glow discharge device.

Geissler tubes, and glow discharge tubes in which the ionization of the molecules of gas remaining in a partially evacuated envelope produces a glow with the usual stratification, are well known for producing illumination and for the visual transmission of signals. Usually such devices have a positive resistance characteristic, although some have been found to possess a resistance characteristic which is negative. It is to be understood that in this application the general mathematical definition of a negative resistance characteristic is

$$\frac{de}{di} = -K,$$

an equation in which K has a numerical value representing the slope of the volt ampere characteristic. The exact equation will be presented hereinafter.

The present invention contemplates the use of a glow discharge tube which is so designed as to give a negative resistance characteristic over a wide range of voltages and which is made sufficiently stable to enable it to be used as a voltage amplifier over a wide range of frequencies. It has been found that a glow discharge tube having a cup shaped cathode in which the glow is produced and substantially a point anode, will have a negative resistance characteristic. Where the glow is diffused outside the cathode, however, a positive resistance results. These tubes are evacuated to a relatively high vacuum and partially filled with a suitable gas. A pressure of 12 mm. has been found to give excellent results if helium is employed, although other pressures and gases may be used. These tubes glow at comparatively low voltages such as 200 volts direct potential or less. When a tube of this type is connected up in series with a positive resistance and an input voltage impressed across both the tube and the positive resistance, a voltage swing greater than the input voltage may be produced across the terminals of either the positive or negative resistance elements, the amount thereof depending upon the characteristic of each element. The perfect case, of course, is where both resistances have the same characteristics but of opposite sign, thereby providing infinite amplification.

The invention will be more fully understood by reference to the following description in conjunction with the accompanying drawings in which:

Figs. 1, 2 and 3 are schematic circuits of three modifications of an amplifier employing a negative resistance glow discharge tube.

Figs. 4 and 5 are schematic circuits of two stage amplifiers in accordance with the invention, using inductance and resistance coupling, respectively.

Fig. 6 is a schematic drawing of a circuit of a three stage amplifier with inductance coupling and supplied from a single power source.

Figs. 7 and 8 are diagrams to aid in the explanation of the action of the tubes as an amplifier in the above circuits.

Referring specifically to Fig. 1 a glow discharge tube 5 has a negative electrode 6 which is formed as a cup shaped metallic electrode which may be cylindrical, spherical, or elliptical in shape, and a wire-like positive electrode 7 which may be placed at right angles to the negative electrode. The positive electrode is positioned so as to produce a glow within the negative electrode 6. A direct voltage from the terminals 9 which may be connected to any type of source of direct current, is supplied to the electrodes 6 and 7 through a protective resistance 10 and choke coils 11 and 12. A bypass condenser 13 is shunted across the supply voltage. In a series circuit including input terminals 14 and electrodes 6 and 7 of the tube 5, is a positive ohmic resistance 15 which preferably has a value substantially equal to the negative resistance of the tube 5. The output terminals 16 of this amplifier circuit are connected across the positive resistance 15 through blocking or coupling condensers 17 in order to limit the direct current to the tube circuit. In this particular circuit arrangement the output is taken from across the positive resistance 15 but it is to be understood that it may also be taken across the tube 5, the present arrangement being preferable however, from the standpoint of stability of operation.

Referring to Fig. 2 in which elements similar to those of Fig. 1 have been given like numerals,

the glow discharge tube 5 has negative and positive electrodes 6 and 7 respectively. In this particular circuit arrangement, the supply terminals 9 for the tube 5 are in circuit with the protective resistance 10, both the terminals and resistance being shunted by a by-pass condenser 18 in order to have only the resistance 15 effective for the amplifying action. The input to this circuit is through an input transformer 19 while the output is across the positive resistance 15 in the same manner as that shown in Fig. 1. It is sometimes advantageous to use the input transformer to match impedances. A simplification of this network is one in which the protective resistance 10 and bypass condenser 18 are omitted altogether and the resistance 15 is used as both the protective resistance and positive output resistance simultaneously. The condenser 18 then bypasses only the source 9. In Fig. 3 the glow discharge tube 5 is shown with its negative electrode 6 as a hollow conical shaped metallic electrode, the positive electrode 7 having its point directed towards the cup formed inside the cone, as also in the case of the cylindrical type electrodes although this is not an absolute requirement. The potential supply terminals 9 are again connected to the tube electrodes through the protective resistance 10 and bypass condenser 18, while the input is through input transformer 19 as in Fig. 2. The feature of this particular circuit is the type of positive resistance employed which in is the form of a resonant circuit comprising a condenser 20 and an inductance 21, which circuit is tuned to a frequency in the neighbourhood of the band of frequencies being amplified. The voltage across the particular combination is emphasized on account of its resonant properties and a more efficient circuit results. The output terminals are taken off across this parallel combination through the bypass condensers 17.

Figs. 7 and 8 illustrate the theory of amplification obtained in the above described circuits. In Fig. 7, curve E_1, shows the relationship between voltage across and current through the positive resistance 15 of Figs. 1 and 2 or across the effective positive resistance resonant circuit 20—21 of Fig. 3; curve E_2 shows the voltage and current characteristics for the tube 5, and curve E the input voltage-current variation across the series circuit including the negative resistance tube and the positive resistance element. The addition of curves E_1 and E_2 produces the curve E or the voltage impressed across the series combination of positive and negative elements. That is, for a current change of *a—b* produced by a voltage ΔE across the series arrangement of the positive and negative resistance elements R and (—R), a voltage change of ΔE_1 is produced across the positive resistance element R, and a change of ΔE_2 is produced across the negative resistance element (—R). The diagram in Fig. 8 represents an arrangement of the positive resistance R and negative resistance (—R) with the respective voltages impressed thereon. It is obvious, therefore, that a small change in impressed voltages across the two resistances in series may produce a larger increase across each respective element depending upon its value and characteristic. Particularizing the general equation given above, the voltage amplification when the output is across the positive resistance is

$$\frac{dE_1}{dE}=\frac{R}{R+(-R)}$$

and when the output is taken across the negative resistance, the voltage amplification equation is

$$\frac{dE_2}{dE}=-\frac{(-R)}{R+(-R)}.$$

The greatest amplification, as shown by the characteristics in Fig. 7, is obtained when the output is taken across the positive resistance since the characteristics are not identical.

Referring to Fig. 4 a two stage amplifier employing glow discharge tubes 25 and 26 having negative electrodes 27 and 28 and positive electrodes 29 and 30 respectively, has the tubes connected in tandem for series amplification of an input voltage impressed upon input transformer 30. The tubes 25 and 26 are similar to the type shown in Figs. 1 and 2 but may have other cup-shaped electrodes. Tube 25 is coupled to tube 26 by a suitable interstage transformer 21 while the output is through an output transformer 32. Output jacks 33, 34 and 35 permit checking the gain obtained in each stage. Tube 25 is supplied from a direct current source 38 through a protective resistance 39 shunted by a bypass condenser 40, while tube 26 is supplied from a direct current source 42 through a protective resistance 43 shunted by a bypass condenser 44. Each circuit of this two stage system operates in a similar manner to that shown in the preceding figures. The effective input impedances of the coupling transformers would for most efficient operation be of the order of the positive resistances. For carrier frequency amplification, the transformers are designed so that they work at their natural period.

In Fig. 5 another two stage amplifier circuit is illustrated which is characterized by resistance coupling and a single power source. The tubes 25 and 26 are the same as those used in the circuit of Fig. 4 with similar electrodes identically numbered. The input of this circuit is through coupling condensers 46 and 47 applying a voltage across resistance 48. Interstage coupling is made through a coupling condenser 48 and resistances 49 and 50 while the output is taken off across a resistance 51 through coupling condensers 52 and 53. This particular circuit is supplied from a single power source 55 each stage being tapped from a potentiometer 56 and 57 shunted by bypass condensers 58 and 59, respectively. This particular power circuit arrangement is preferable because of the characteristics of the glow tubes 25 and 26. For instance, should the tubes be connected across the same resistance in parallel, an unstable condition is created because of the negative characteristics of the tubes, as the first tube may operate at a lower voltage than the other tube. Of course, with care, the tubes can be made to operate in parallel. However, with the potentiometer arrangement as shown, the proper polarization of the tubes is obtained and a stable condition exists.

In Fig. 6 a three stage negative resistance amplifier is shown employing three glow discharge devices 60, 61 and 62 with appropriate electrodes similar to those employed in the preceding circuits. This circuit has an input transformer 63, interstage transformers 64 and 65, and output transformer 66. It is supplied from a single power source 68 through a potentiometer having series resistances 69, 70 and 71 and respective bypass condensers 72, 73 and 74. It is to be observed that in this circuit, as well as that shown in Fig. 5, that these potentiometer resistances which provide the proper polarization to the tubes also

serve as protective resistances, preventing an excess of current through the tubes.

An important feature of these amplification circuits is the pronounced simplicity of the apparatus required, while the gain obtained therein is comparable to a similar arrangement of three element thermionic vacuum tubes. The power supply of these tubes is of the simplest nature, the energies required for their operation being small compared with the present day type of vacuum tubes employed for similar purposes, while the connecting circuits are extremely simple and employ a minimum of apparatus. The transmission through the amplifiers, as disclosed, is of the highest quality.

Through experiments and tests of single and plural stage amplifiers of this type, voltage gains of from 4 to 8 fold per stage, have been obtained, and there is no doubt but that larger gains can be obtained with more refined apparatus.

Another feature of the invention is the simplicity of the tubes necessary to produce this amplification since the tube itself requires only two electrodes. These tubes are not critical when constructed as disclosed above, care being taken to maintain the glow interior of the cup type negative electrode. The elements therein may be positioned at any angle, the right angle relationship however, having been found preferable from a construction standpoint. With a radio receiver constructed in accordance with this invention, a very high quality amplification may be obtained with the best economy of any type of amplifier known at present.

Other adaptations of the circuit may readily occur to those skilled in the art and it is to be understood that the invention is limited only by the scope of the appended claims.

What is claimed is:

1. In an electrical amplifying system, a glow discharge tube having two electrodes, one of said electrodes being cup shaped, a second electrode for said tube in juxtaposition to said cup shaped electrode, a polarizing source for said electrodes to produce an ionization discharge only within said cup shaped electrode whereby said tube is caused to have a negative resistance characteristic, and input and output circuits for said tube.

2. An amplifier circuit comprising, a glow discharge device having a substantially cup shaped cathode, an anode in juxtaposition to said cathode, input and output circuits for said device, and a source of potential for polarizing said cathode and anode whereby an ionization glow discharge is produced within said cathode only to cause said discharge device to exhibit a negative resistance characteristic.

3. In an electrical amplifying system, a glow discharge device having a plurality of electrodes, an input circuit for said device, an output circuit for said device and a source of potential for polarizing said electrodes to produce an ionization discharge within one of said electrodes to cause said device to have a negative resistance characteristic.

4. In an electrical amplifying system, a glow discharge tube having two electrodes, a source of potential for polarizing said electrodes to produce an ionization discharge therebetween, an input circuit for said tube, an output circuit for said tube, said ionization discharge being substantially localized within one of said electrodes to cause said tube to have a negative resistance characteristic for producing a difference in amplitude between the voltages in said input and output circuits.

5. In an electrical amplifying system, a plurality of glow discharge devices connected in tandem, means for impressing on one of said devices voltages to be amplified, means for obtaining from the output circuit of another of said devices amplified voltages, means for connecting said devices and means for polarizing the electrodes of all of said devices to produce ionization discharges within one of the electrodes of each of said devices to cause each of said devices to have negative resistance characteristics.

6. In an electrical amplifying system, a plurality of gaseous glow discharge tubes, each having input and output circuits, a cup shaped electrode for each of said tubes, a wire like electrode for each of said tubes in juxtaposition to each of said cup shaped electrodes respectively, a source of potential for polarizing said electrodes to produce ionization discharges within said cup shaped electrodes whereby said devices are each caused to exhibit negative resistance characteristics, and transformers for coupling said input and output circuits.

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